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MDPI

Review

Agricultural Waste as a Reinforcement Particulate for Aluminum Metal Matrix Composite (AMMCs): A Review

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Abstract: The desire to create sustainable development through research birthed this study. Over time, several authors have focused on the utilization of various chemical particulates as reinforcement constituents for metallic matric composites (MMCs) and aluminum metal matrix composites (AMMCs), which has thus far yielded positive outcomes for achieving the chemical, mechanical, microstructural, thermal, corrosion, and wear property improvement of various reinforced composites. However, this study focused on the search for the residing potentials in alternative materials that can be used as reinforcement particulates in place of the commonly used graphite, silicon nitride, titanium nitride, zirconium, and the likes. This study literarily revealed, via several reviews of literature, that the search for less expensive and easily procured materials with a silicon oxide and magnesium oxide chemical content instigated the utilization of materials from agricultural waste (agro-waste). According to the reviewed literature, some of the waste materials from agriculture that have been found to be useful for the particulate reinforcement of composites are groundnut shell, coconut shell, rice husk, breadfruit seed hull ash, aloe vera, bean pod ash, cow horn, and so on. It was discovered that processed agro-wastes in the form of powdery particulates have demonstrated great reinforcing abilities, as recorded in literature. In addition, they enhanced the mechanical properties of the various composites developed in comparison to the as-cast materials.

Keywords: agro-waste; particulate; fiber; composite; metal matrix composites (MMCs)

1. Introduction

In the contemporary world of engineering, various materials, amongst many others like mild steel, aluminum, cast iron, copper, stainless steel, and galvanized metals, have been greatly utilized in several applications [1]. These applications vary for diverse industries, ranging from aerospace, power generation, chemical processing, military, automotive, fashion and apparel, oil, gas and petroleum processing, biomedical, sports, and construction industries [2–4]. Engineering materials go through many processes in the production chain, like machining, welding, bending, and casting [5]. An array of factors or criterion are immensely considered when making the decision of the choice of material that is to be used in order to carry out a specific engineering task. Some of these factors are rigidity, tensile strength, thermal conductivity, creep, weldability, ductility, malleability, plasticity, machinability, fatigue, hardness, toughness, corrosion resistance, electrical and conductivity [6]. Upon the consideration of these factors as very germane requirements for specific use in different engineering applications over the years, some of the materials have been found to be deficient in certain areas, due to their shortcomings, such as poor ductility, weak strength, low thermal conductivity, and poor machinability [7]. These limitations have been a major challenge in the engineering sector, owing to some of the difficulties encountered in material selection for some specific operations and purposes. As a result of this major challenge, several researchers from various research institutes and academic institutions have worked on solving these problems of the mechanical, thermal, physical, chemical, microstructural, and macrostructural properties engineering materials, related to all engineering industries where specific applications occur.

According to the literature [8–11], there have been improvements in the mechanical properties of some of the engineering materials via the discovery of composites in the form of metal matrix composites, and the different types of particulates used for reinforcement in metallic matric composites (MMCs) are silicon nitride, boron nitride, alumina, and titanium carbide. Aluminium matrix composites (AMMCs), which are the major focus of this review, are very good materials that are used for various scopes of engineering applications because of their robust mechanical and physical properties [12–14]. It was clearly stated by the authors of [15], that the reinforcement constituents added to metallic matrix contribute to improving the wear, fatigue, stiffness, creep, and strength properties relative to the conventional engineering materials.

Amongst the many authors and researchers that have worked on AMMC and MMC, Natarajan et al. [16], Zhang et al. [17], Ochieze et al. [18], and Panwar et al. [1] have validated the substantial benefits of aluminum matrix composites and metal matrix composites in comparison to the popularly known conventional engineering materials. However, the use of naturally sourced particulates (agro-waste) has been discovered to be a very good reinforcement constituent, owing to the availability and immensely low-cost of acquiring the recommended agricultural waste. So, many researchers have worked extensively on several natural wastes from agriculture, and have found them to rich in silicon and magnesium oxide constituents, among others [19]. A few of the widely recognized agro-wastes are coconut shell, groundnut shell, cow horn, corn cob ash, and bagasse.

It was reported by the authors of [20], that some typical agricultural wastes, like bagasse, rice husk ash, corn cob ash, bamboo leaf ash, corn stalk ash, and palm kernel shell ash, are regularly used agro-waste reinforcements for metallic matrix composites. The advent of the importance of agricultural waste in particulate form as a reinforcement for metallic matrix composites is not just of added advantage to our manufacturing industries because of its availability and low cost, but it also reduces the rate of environmental pollution, by converting such waste from agro-processes into useful raw materials for engineering purposes [21].

2. Review of Literature

Saravanan and Kumar [19] carried out an experimental study in order to determine the likelihood of improving the mechanical properties of (ALSi10Mg) by reinforcing it with a material that is relatively cheap and available locally. Rice husk ash was used as the particulate for the experiment. The constituent of the rice husk ash that was used was in varying percentages, such as 3%, 6%, 9%, and 12% per unit weight, as the reinforcement in the development of MMC (metal matric composite) with the aid of liquid metallurgy. Upon the characterization of the samples with the use of SEM (scanning electron microscope), an analysis of the rice husk ash (RHA) particle distribution was done. The RHA particles were well spread in the aluminum matrix, and thus the hardness and the tensile strength of the composite were improved. The area interface was increased between the RHA particles and the developed matrix.

Ochieze et al. [18] experimentally studied the wear parameters and their effects on the wear characteristics of an A356 alloy that is fully reinforced with a particulate called corn horn. The cow horn particles were produced via the sintering of the spark plasma. The Tahuchi's (L9) technique was used to carry out the experimental investigation. The wear test was done with the aid of a tribometer, and the surface morphology was carried out with the use of a scanning electron microscope. It was discovered that the reinforced A356 alloy exhibited a better sliding resistance to the wear compared with the virgin material (unreinforced A356 alloy). The study experimentally confirmed the effect of the corn horn particulate as a reinforcement material for the aluminum alloy composite by immensely increasing the composite's wear resistance.

Hima Gireesh et al. [22] used aloe vera powder to reinforce the aluminum metal matrix in order to study the mechanical characterization of the AMMC. He reported that fly ash had been used as a reinforcement particulate for the aluminum metal matrix by several researchers, but his study reported that the use of aloe vera significantly reflected an improvement on the mechanical properties of the AMMC in regards to tensile strength, impact strength, and hardness, compared to the popularly known and used fly ash.

Nwobi-Okoye and Ochieze [23] experimentally studied the behavior of aluminum alloy A356 reinforced with a particulate composite of cow horn, for application in a brake drum via the use of an artificial neural network (ANN), response surface methodology (RSM), and simulated annealing. The study was focused on modelling the age hardness process on the developed or reinforced AMMC using ANN and RSM. The result revealed that the modelling via ANN that generated the data for age hardening was improved by 0.9583 predictions compared with that of RSM of 0.9921 predictions of ANN.

Atuanya and Aigbodion [12] used the ash from bean pods to reinforce the Al–Cu–Mg alloy, through the double layer feeding stir casting method. The study was focused on the microstructural and properties evaluation of the bean pod ash (BPA) particulate reinforced aluminum alloy. The nanoparticles were used within the variance of 1 to 4 wt % in order to produce the aluminum matrix composite. The evaluation was done in order to know the hardness, impact strength, and tensile energy of the reinforced composite, with the use of SEM and XRD. The outcome of the experiment showed that the interphase bonding that was achieved was very robust, with a substantial increase in the hardness and tensile strength at 4 wt %, by 44.1% and 35%, respectively. Despite the seemingly low or light percentage weight of the particulate, there was an improvement in the mechanical properties of the AMMCs.

Atuanya et al. [24] studied the properties and the microstructural characterization of an Al–Si–Fe alloy reinforced with ash from breadfruit seed hull as particulate composites. A 500 nm particulate size was examined, with an investigation of six varying fractional weights of the ash particles from the breadfruit seed hull. There was a very good bonding between the AMMCs and the breadfruit seed hull ash particulate, resulting in improved mechanical properties of the composite, except for a very slight decrease in the impact strength.

Alaneme et al. [25] reported on an experiment carried out on the study of the fracture, mechanical, and microstructural properties of silicon carbide and groundnut shell ash particle reinforced aluminum metal matrix composites (AMMCs). A varying mix of ratios of 0:10, 2.5:7.5, 5:5, 7.5:2.5, and 10:0 were used for the groundnut shell ash and silicon carbide particulate mixture. The phase of reinforcement was constituted by 6 and 10 wt % of the particulate mix ratio. The characterization analysis showed that there was an improved percentage elongation, and it was constant with the increased content of the groundnut shell ash (GSA), but with the increasing content of GSA, there was a significant increase in the fracture toughness.

Alaneme and Olubambi [26] studied the wear and corrosion behavior of an Al–Mg–Si alloy matrix as a hybrid composite reinforced with alumina and rice husk ash particulate. The particulate was used at a constituent 2, 3, and 4 wt % in order to prepare 10 wt % of the phase reinforcement with the AMMCs. The corrosion behavioral analysis was done using a potentiodynamic polarization measurement and open circuit corrosion potential (OCP). The wear behavioral study of the composite was carried out using the coefficient of the friction parameter. The study showed that there was a superior resistance to corrosion from the reinforced composite (Al–Mg–Si) with 10% Al_2O_3 to that of the hybrid composite in a solution of 3.5% NaCl.

Mishra et al. [27] observed the mechanical behavior or properties of aluminum alloy (LM6) as a metal matrix composite reinforced with rice husk. A rice husk ash (RHA) particulate of 6% was used as the reinforcing constituent, and the aging process was artificially carried out at varying temperatures

(135 °C, 175 °C, and 225 °C). The metal matrix composites (MMCs) were developed via the stir casting method. The results showed an improvement on the hardness value in the as cast form, from 54.8 HRB to 78.4 HRB for the composite at 175 °C.

3. Extracts from Various Technological Methods

An outline of some of the contributions made by some selected researchers in the study of MMCs and AMMCs are shown in Table 1.

Table 1. List of authors and their contributions to knowledge.

Authors	Highlights/Contributions	Technologies
Sahoo et al. [28]	• A versatile and very simple technique was proposed for surface composite preparation at a low ambient and temperature processing conditions. • The proposed technique revealed its best properties for the surface graphitization of Al-6063.	• SEM [1] • EDS • XRD [1]
Raja and Sahu [29]	• Experimental studies carried out show that the B_4C sample yielded a better and improved hardness value.	• Powder Metallurgy • SEM • RHTM [1]
Alizadeh and Baharvandi [30]	• The B_4C particles reduced the compressibility of milled powder. • The effect of B_4C results in a greater yield strength for the composite compact. • Nano B_4C coherently enhances the formation of interfaces within Al grains, which inhibit pull out.	• Ball Milling • STEM [1] • XRD
Elanchezhian et al. [31]	• A study on the mechanical properties of jute, sisal, and abaca was done. • The results show that the fibers can be used in storage devices like grain storage silo and bio gas containers. • The fibers can be used in transportation, for automobile and railway coach interiors. • The study also showed that the fibers are ecofriendly, non-abrasive, and possesses biodegradable characteristics.	• UITM [1] • RHTM
Hassan and Aigbodion [15]	• An investigation was done on the hardness parameters of heat-treated Al–Si–Fe/SiC. • The study revealed that the hardness increased with the percentage increase in the silicon carbide added to the alloy.	• RHTM
Natarajan et al. [16]	• A study was carried out on the wear behavior of aluminum composite (A356/25SiC_P). • The metal matrix composites (MMCs) have a relatively higher resistance to wear compared to the conventional grey cast iron.	• Stir casting • Optical micrograph
Zhang et al. [17]	• An investigation into the impact of pre-oxidized β-Si_3N_4 whiskers on the mechanical and microstructural properties of aluminum matrix composite. • The results show that the mechanical properties and the relative densities increased.	• Hot pressing method • TEM [1] • Vickers hardness test

Table 1. *Cont.*

Authors	Highlights/Contributions	Technologies
Rao et al. [12]	• A study was carried out the effect of particle size on mechanical properties of Al-RM_P metal matrix composites • An improved hardness and compressive strength were obtained alongside an increase in the tensile strength of the aluminum metal matrix composites (AMMCs).	• Stir casting • SEM
Sachit et al. [9]	• An experimental study was done on the role of particle size on the tribological and mechanical behavior of LM4-/SiCp-based MMC. • Silicon carbide particulate was used in two varying particle sizes as the reinforcement for the composite. • The study revealed that there was an increase in the mechanical properties, with respect to a decreasing particle size. • It also showed that the wear properties relatively increased with the increasing particle size.	• Stir casting • SEM
Liu et al. [32]	• An experimental investigation was done on the effect of the aluminum content on the mechanical and microstructural properties of as cast Mg–5Nd alloy. • The results present that the tensile strength, elongation, and yield strength of the as cast Mg–5Nd–3.0Al alloy had a significant enhancement of 72.4%, 264.0%, and 45.3%, respectively, compared with the as cast Mg–5Nd alloy.	• SEM • XRD • Optical microscope
Senthilvelan [33]	• SiC and B_4C nanoparticles enhance the hardness and tensile strength of the nanocomposite compared to the pure alloy.	• Ultrasonic cavitation • SEM

[1] The meaning of the acronyms used in Table 1 is given in full below. SEM—scanning electron microscopy; XRD—X-ray diffraction; STEM—scanning transmission electron microscope; TEM—transmission electron microscopy; UITM—universal impact testing machine; RHTM—Rockwell hardness testing machine.

A list of some of manufacturing processes/techniques of the MMCs as reported by some researchers is shown in Table 2.

Table 2. List of the various available methods/techniques used in MMCs manufacturing.

S/N	Manufacturing Techniques	Authors
1	Powder metallurgy	Basak [34]
2	Physical vapour deposition	Ulmer et al. [35]
3	Oxidation treatment	Urena et al. [36]
4	Stir casting	Sarada et al. [37]
5	High energy ball milling	Mendoza et al. [38]
6	Mechanical alloying and hot extrusion	Deaquino et al. [39]
7	Spark plasma sintering	Sweet et al. [40]
8	Pressureless infiltration	Xie et al. [41]
9	Ultrasound assisted solidification	Neeraj et al. [42]
10	Stir casting with the vortex method	Akbari et al. [43]
11	Stir casting	Khorramie et al. [44]

Some of the selected agricultural wastes with their peculiar chemical composition/constituents are shown in Table 3.

Table 3. Nominal chemical composition of agro-wastes [45].

Agro-Waste		**Chemical Composition**									
		Al_2O_3 (%)	**CaO (%)**	**Fe_2O_3 (%)**	**K_2O (%)**	**MgO (%)**	**Na_2O (%)**	**SiO_2 (%)**	**SO_3 (%)**	**P_2O_5 (%)**	**Li_2O * (%)**
Rice husk ash	Before treatment	4.10	0.34	0.64	2.15	0.64	0.15	91.6	-	-	-
	After treatment	3.06	0.56	0.15	2.67	0.73	0.36	91.6	-	-	-
Fly ash	Before treatment	29.60	0.10	0.72	3.53	0.34	-	64.6	-	-	-
	After treatment	25.60	0.10	0.69	3.14	0.56	-	69.5	-	-	-
Palm oil clinkers		3.50	2.30	5.18	4.66	1.24	81.8	0.76	-	-	-
Palm oil fuel ash		5.45	7.50	-	5.30	3.93	-	49.20	1.73	6.41	13.85
Coconut shell ash		5.45	0.57	12.40	0.52	16.2	0.45	45.05	-	-	-

* Li_2O is Lithium oxide.

The mechanical effect of the particulate on interfacial bonding is shown in Figure 1a–c [46]. The outcome of the elemental material monograph reveals the particle size of the RHA and fly ash to be 23 µm and 15 µm, respectively, in comparison to the 36.04 µm particle size of the A356 alloy (Figure 1a).

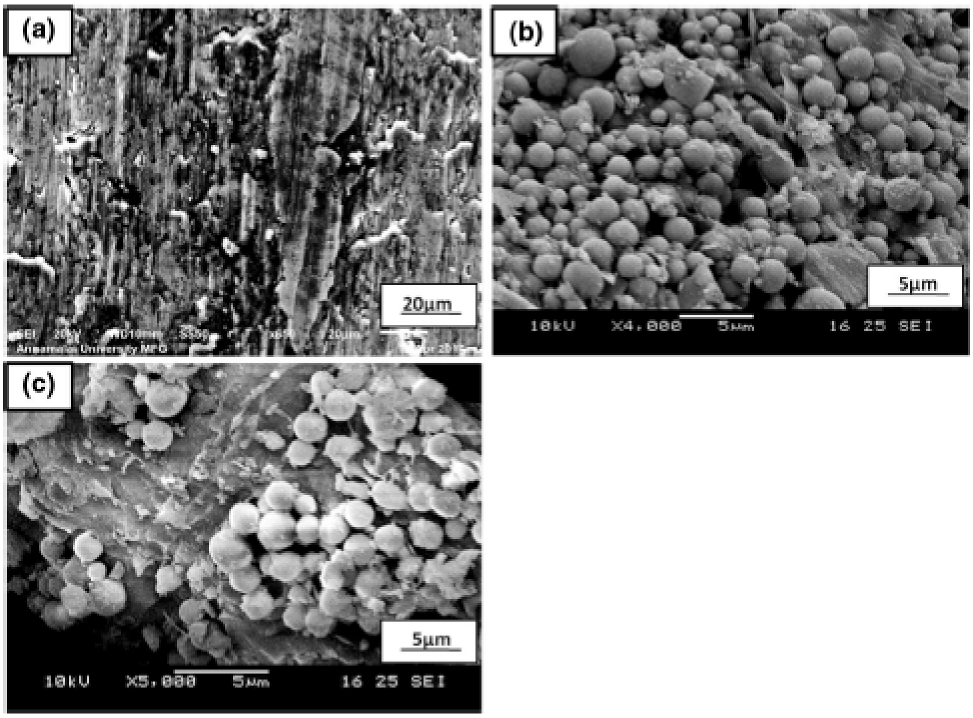

Figure 1. (**a**) A356 alloy; (**b**) particles of rice husk ash (RHA); (**c**) particles of fly ash. Source: Vinod et al. [46].

The particulates were seen to have a significant influence on the mechanical properties of the materials, as depicted by the reduction of the particle clustering and the improved uniformity of the particle distribution.

4. Conclusions

This study has shown that agricultural waste materials are of very high economic value and importance, owing to their various utilizations as reinforcement particulates to several aluminum series in the form of aluminum metal matrix composites (AMMCs) and metal matrix composites (MMCs). Agro-wastes are gradually gaining grounds predominantly as material particulates in the field of materials engineering, owing to the potential constituents that reside in some of them. Part of the added profiting of the waste from agriculture is the reduction of excessive environmental pollution via the release of harmful oxides into the atmosphere through the decomposition processes, being disposed of around human communities, through incessant and indiscriminate littering and burning. The results of the reviewed literature suggest and encourage researchers in the field and focus of materials, production, and manufacturing engineering to further harness the potential of the agro-wastes that are obtainable in our immediate environment.

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